Notes on the Limnology of Itkillik Lake, Gates of the Arctic National Park, Alaska

Final Report to the National Park Service

Gates of the Arctic National Park and Preserve
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Introduction

This report summarizes limnological data collected from Itkillik Lake during 7-13 July 1989. Our purpose was to document physical and chemical conditions in this remote waterbody, particularly as they affect the biomass, distribution, and nutrient limitation of planktonic algae.

This project follows a limnological survey of Walker Lake in 1988 (Jones et al. 1990). That study showed Walker Lake is oligotrophic as judged by phosphorus concentration and algal biomass estimated as chlorophyll-*a*, but its nitrogen content was higher than expected in an unproductive waterbody. The source of nitrogen in Walker Lake is likely from nitrogen-fixing lichens in the watershed. Nutrient addition experiments there clearly demonstrated phosphorus limitation. Planktonic algae in Walker Lake responded to phosphorus additions but not nitrogen. It seems that nitrogen is present in this system in excess of the amount needed for algal growth. These findings, along with limnological data the U.S. Fish and Wildlife Service collected in 1987 on Walker Lake and the Chandler lakes (Jones et al. 1990), led us to hypothesize that because of the prevalence of nitrogen-fixing lichens in the alpine tundra, nitrogen may be abundant relative to phosphorus in the surface waters of this part of Alaska. If this assumption is true, then phosphorus limitation of the phytoplankton might be typical of lakes in the Gates of the Arctic National Park and Preserve. This hypothesis has important implications for lake management and our investigation of Itkillik Lake was its first test. Itkillik Lake was selected for study because it represents an extreme contrast to Walker Lake. Itkillik Lake is a small shallow waterbody located on the north side of the Brooks Range whereas Walker Lake is a large deep lake on the south side of the range.

Site Description

Itkillik Lake (68°24'N, 149°55'W) is on the north-facing slope of the Brooks Range near the northeastern end of the Endicott Mountains in the Gates of the Arctic National Park and Preserve (Figure 1). It is a narrow elongate basin with two depressions; each is about 12 meters maximum depth. The lake is 4.5 km long with a north-south orientation. Its surface area is 393 ha, volume 22.8×10^6 m^3, mean depth 5.8 m, and shoreline length 10.8 km.

Methods

Water samples were collected from three stations in the lake, six inlet tributaries, and the active (southern) outlet (Figure 1) into Cubitainers® and returned to the field camp where aliquots were distributed to glass tubes for total nitrogen and total phosphorus analyses, and to small Nalgene® bottles for anion and cation analyses. Planktonic samples were taken into Cubitainers and placed into a dark cooler until filtered as below at the field camp. Lake samples were taken at discrete depths with a 2-L PVC Van Dorn bottle suspended on marked airplane cable wire-line, and stream samples were grab samples taken directly into the Cubitainers.

Periphytic chlorophyll-*a* samples were taken by scrubbing rocks clean around a quarter (coin) and then scrubbing the algae previously protected by the quarter onto glass fiber filters and handled as below. The rocks were obtained from random spots in 0 to 0.5 m of water near camp. Periphytic and planktonic chlorophyll-*a* samples were filtered onto glass fiber filters using a hand vacuum pump. Care was taken to keep the vacuum below 20 cm of mercury to avoid breaking and lysing cells. Most analyses were conducted in duplicate or triplicate at the University of Missouri using standard methods (APHA et al. 1985). Alkalinity was measured by the HACH digital titrator® method, and pH with a portable HACH ONE® pH meter immediately after sample collection. Total nitrogen was measured on acid-preserved (H_2SO_4) samples after persulfate digestion (D'Elia et al. 1977) followed by cadmium reduction to nitrite. Total phosphorus was measured by the molybdosilicate method after persulfate digestion (Eisenreich et al. 1975). Chlorophyll-*a* and its breakdown product, phaeophytin, were determined by fluorometry (Knowlton 1984) after extraction in hot ethanol (Satory and Grobbelaar 1984). Cations were determined on acid-preserved samples using a flame photometer or atomic adsorption spectrophotometer.

Nutrient stimulation bioassay experiments (after Wurtzbaugh et al. 1985) were run at a north and south station in the lake by partitioning unfiltered lake water among 10-L translucent polyethylene containers (Cubitainers) and, after adding the test nutrients (5 µg/L phosphorus and/or 100 µg/L nitrogen), suspending the Cubitainers at a 4-m depth where they incubated for four days. After retrieving the Cubitainers, each was subsampled three times and the subsamples filtered for chlorophyll analyses (conducted as above). These chlorophyll data were transformed to inverse square roots (to normalize) and analyzed in a one-way analysis of variance.

Temperature and dissolved oxygen profiles were obtained in situ using a YSI Model 57 DO meter with a 15-m cord to the Clark-type membrane-covered polarographic probe. Light penetration was measured with a LiCor LI-188B integrating quantum (radiometer) photometer attached to an LI-192SB underwater cosine quantum sensor with a 25-m cord. Secchi depth was measured in situ with a standard 20-cm Secchi disk. Wherever average values are reported below, they are as the mean ± the standard deviation.

Results and Discussion

Major Ions and Salinity

The water of Itkillik Lake (Table 1) was of the bicarbonate type, dominated by calcium (Ca^{+2}) among the cations (74%) and bicarbonate (HCO_3^-: from alkalinity as $CaCO_3$) among the anions (91%). Among the remaining major cations magnesium (Mg^{+2}) accounted for 19%, potassium (K^+) 6% , and sodium (Na^+) 6%. Additional anions were 8% sulfate (SO_4^{-2}) and about 1% chloride (Cl^-). This ionic composition suggests carbonate materials are extensive in the watershed. Salinity in Itkillik Lake was nearly twice the world average for freshwaters (cation equivalent 2.60 meq/L versus 1.42 meq/L) and from 2 to 10 times higher than reported in other Brooks Range lakes (Jones et al. 1990). The relatively low amount of sulfate in Itkillik Lake is more typical of Arctic Slope lakes (Kalff 1968) than of other Brooks Range lakes (Jones et al. 1990).

Salinity of the inflowing streams (Table 2) was dominated by Ca^{+2} and HCO_3^-, and the total ion content (discharge weighted) was some 50% greater than the lake water (cation equivalents 4.1 versus 2.6 meq/L) (Table 2). The streams were sampled during basal (low) flow and these high salinity values likely reflect the ion content of groundwater within the watershed. Salinity in the streams would be much lower because of dilution by runoff during periods of snowmelt or intense precipitation.

Nutrients

Total phosphorus (TP) in Itkillik Lake averaged 5 ± 1 µg/L (parts per billion) and total nitrogen (TN) averaged 330 ± 70 µg/L in the 34 lake samples collected during the study (Appendix 1). These low nutrient concentrations indicate that Itkillik Lake is oligotrophic. The mean ratio of TN:TP (by weight) in Itkillik Lake was 78. Limnologists consider that in lakes with TN:TP > 20, nitrogen is present in excess of algal needs and phosphorus is the element limiting the phytoplankton (Dillon and Rigler 1974; Smith and Shapiro 1981). Nutrient concentrations in the streams were similar to measurements in the lake (Table 4) and the discharge-weighted ratio of TN:TP was 138. These values indicate that, at least during periods of basal flow, nitrogen is abundant relative to phosphorus in stream input to Itkillik Lake.

In seven samples from the lake, particulate organic carbon (POC) averaged 1823 µg/L and particulate organic nitrogen (PON) averaged 238 µg/L. This PON measurement suggests that some 72% of the TN in the system is present in the organic fraction (assuming a lakewide average of 330 µg/L TN). The ratio of POC:PON (wt:wt) in these samples was 7.7, a value that closely matches the empirical average ratio (7.8) of these two elements in algae (Healey

1973). Therefore, we speculate that most of the organic particulates in this lake were algal cells.

Silica in the lake (1.4 ± 0.2 mg/L) and inflows (2.3 mg/L) (Appendix 1) were about one-tenth, or less, of the silica content of Walker Lake (Jones et al. 1990). The low concentration of silica may become limiting to diatoms at times and other algae may then be favored. Livingstone et al. (1958) report that low silica content is common in many Alaskan lakes.

Algal Biomass

Algal chlorophyll averaged 0.89 ± 0.31 µg/L in 39 samples collected from the lake (Appendix 1). Individual values ranged between 0.57 and 1.87 µg/L, and the distribution of these values was closely associated with thermal stratification. Values < 1 µg/L were measured in samples from the freely circulating epilimnion (the top, warmed layer), whereas values > 1 µg/L were measured in the cool, deep layers (metalimnion and hypolimnion) of this stratified lake. As an example, the distribution of algal chlorophyll throughout the water column at Site II on 8 July 1989 is presented in Figure 2. Algal chlorophyll values were about 0.6 µg/L within the epilimnion (0 to 5 m) and increased to 0.9 µg/L at 7 m, concurrent with an appreciable decrease in water temperature within the metalimnion. A maximum value of 1.53 µg/L was measured at 9 m within the hypolimnion of this lake. A similar pattern was measured at more than one site and more than one day during our brief study of Itkillik Lake (Table 3 and Appendix 1).

Subsurface algal peaks are common in stratified lakes that are sufficiently transparent for photosynthesis to occur deep within the water column (Pick et al. 1984). In Itkillik Lake the subsurface peak occurred within the metalimnion at about the Secchi depth (9 to 10 m). Light measurements show that about 5% of the surface light is present at this depth (Figure 3). Subsurface algal peaks were also found in Walker Lake at the 5% light level, which was much deeper (~ 15 m) in that more transparent lake. Phaeopigments (breakdown products common in dead or unhealthy algal cells) were a small proportion of the total chlorophyll pigments present in all the samples we collected from the lake, even those from the metalimnion and hypolimnion (Appendix 1). This finding suggests that the subsurface layer was composed of healthy cells that may be photosynthetically active at depth and the resultant low light levels.

Our data do not enable us to determine whether the subsurface chlorophyll layer in Itkillik Lake results primarily from in-situ growth of algae or from the settling of algal cells from the surface water. Nor can we judge whether the subsurface peak persists throughout the summer in this waterbody. When we began measurements on 8 July the lake was weakly stratified, with epilimnetic temperatures between 13.5 and 14.3°C, metalimnetic temperatures of about 12°C, and hypolimnetic temperatures of around 10°C (Table 5). However, early on

10 July (about 9 a.m.), a strong wind rose and continued until we left on 13 July. Wind mixing and associated cooling of the surface waters and heating of deeper waters (Figure 4) were sufficient to break down thermal stratification by noon on 11 July (Table 5). If this weather pattern is typical of conditions on the northern side of the Brooks Range during summer, then we suspect Itkillik Lake is polymictic—that is, it stratifies during periods of warm, calm weather and then mixes during periods of cool, windy weather. If this is the case, then algal peaks are a phenomenon of the stratified periods and are likely quite temporary throughout the summer, being mixed through the water column when wind destratifies the lake.

A subsurface algal peak was also found in Walker Lake, but it was associated with strong thermal stratification. Collectively, these findings raise the question of whether subsurface algal peaks are common throughout the lakes of the Brooks Range.

Itkillik Lake supports a standing crop of benthic algae (periphyton) on its rocky substrate that is apparent as a green and brown scum to an observer standing on the shoreline. In the vicinity of the camp we found that benthic chlorophyll in the shallow littoral zone (< 0.5 m) averaged 17.6 ± 12.7 mg/m^2 (n=18). Studies in lakes elsewhere have shown that benthic periphyton is an important primary producer (Cattaneo and Kalff 1980, Welch and Kalff 1974) and could be an important source of carbon fixation in clear, oligotrophic lakes like Itkillik. Based on field observations, periphyton is also prevalent near the shores of Walker Lake.

For the purpose of comparing the relative amount of planktonic and periphytic algal biomass in Itkillik Lake, we assumed that on average the water column contained a total of about 5 $\mu g/m^2$ of algal chlorophyll (calculated using the average volumetric concentration of algal chlorophyll within our samples—0.89 µg/L—and the mean depth of the lake—5.8 m). We can estimate from our data that the standing crop of periphytic algae (as chlorophyll-*a*) represented about 40% of the standing crop of planktonic chlorophyll-*a*. This assumes that our periphytic chlorophyll-*a* value is representative of 0 - 1 m around the lake, and that our overall average phytoplankton chlorophyll-*a* value is representative of the water column average over the whole lake area. This comparison is preliminary because it is based on only a few measurements of periphyton from the shallow waters in a restricted region of the lake. However, it points out the potential importance of periphyton in this shallow, clear lake and raises questions about where primary production occurs in this waterbody. Field observations suggest that periphyton was widespread along the shoreline and on the deep substrates (1 to 3 m, perhaps deeper) of Itkillik Lake. Therefore, the distribution of periphytic algae should be evaluated further in Itkillik Lake, along with production measurements of both the periphyton and phytoplankton, to document the role of periphyton in this system.

Nutrient Enrichment Experiments

Based on the TN:TP ratio in this waterbody we would have expected phosphorus to be limiting algal growth and nitrogen to be present in excess. Unexpectedly, nitrogen limitation was demonstrated by the results of nutrient enrichment experiments conducted in situ at Itkillik Lake (Figure 5). At both sites algal chlorophyll was significantly greater than the control in the nitrogen treatment, and growth was even greater at the north site in the treatment that included both nitrogen and phosphorus. Algal growth was slightly stimulated by phosphorus at the south site (Station I) but not at the north site (Station III).

Two related hypotheses might help explain the result of this experiment: (1) not all of the nitrogen in Itkillik Lake is present in a form that is available to phytoplankton; and (2) nitrogen additions in this experiment were in the form of ammonium—an energetically available form of nitrogen that may have artificially stimulated the growth of certain components of the phytoplankton community. Studies in nearby Toolik Lake have shown that both nitrogen and phosphorus have been found to stimulate phytoplankton in various studies (Miller et al. 1986, Whalen and Alexander 1986). This could also be true of Itkillik Lake despite the proportionately high nitrogen and low phosphorus concentrations measured at the time of our study.

Summary and Conclusions

Because Itkillik Lake is shallow (maximum depth ~12 m) and exposed to the climate of the northern side of the Brooks Range, summer stratification is probably repeatedly broken by wind events. The relatively weak stratification we observed early the first morning (3:40 a.m.) that we were at the lake was probably weakened by the intense solar heating observed in the profile taken 7 hours later, and was completely broken by the wind event that began the morning of 10 July 1989 (Table 5). This characteristic of low thermal stability probably adds dissolved oxygen to the lake periodically throughout the summer, but resuspension of bottom sediments may increase the biochemical oxygen demand exerted throughout the water column using up this added dissolved oxygen. Resuspension may also be a factor in nutrient availability to the algae.

When the lake was visited on 22 August 1988 by National Park Service (NPS) personnel, the surface temperature was 11.3°C. This indicates that autumnal cooling may begin sometime before late August.

Light penetration (Figure 3) is probably also influenced at times by resuspension of sediments, but the lake was quite transparent to light when calm on 9 July 1989 with the 1% light depth calculated as 14.5 m, which depth is beyond the bottom of the lake. The Secchi depth was measured earlier, on 8 July 1989, as 9.6 m and 9.7 m at Station I, but the disk was visible on the bottom of the lake at about 10.1 m the next day, just after the light penetration measurements were taken nearby (Figure 3). No Secchi depth measurements were attempted during the wind event.

Alkalinity in Itkillik Lake was about 50% higher than in Walker Lake, which was high for lakes of that region (72 mg/L as $CaCO_3$ versus 29 mg/L at Nutuvukti Lake) (Jones et al. 1990). Therefore, Itkillik Lake is relatively more resistant to changes in pH and has more available carbon than other Brooks Range lakes.

Scouring rush (*Equisetum* sp.) was the dominant vascular aquatic plant observed by us and by the NPS in 1988. Aquatic buttercups, *Ranunculus* sp. and *Hippurus* sp., were also found nearshore in the vicinity of Stream #4.

Snails were noted to be quite numerous and of good size in this lake. This is an indication that there are adequate minerals available in the water for shell formation, and that there is adequate benthic algae for snail food.

Itkillik Lake is an oligotrophic waterbody, a condition typical of lakes in the Gates of the Arctic National Park and Preserve (Jones et al. 1990). Itkillik Lake has a higher phosphorus and algal biomass and a lower nitrogen content than Walker Lake. These differences in the content and proportion of the major plant nutrients in these two waterbodies likely account for the observed differences in the nutrient stimulation tests conducted in both lakes. Phosphorus limitation was clearly demonstrated in Walker Lake, whereas phytoplankton in Itkillik Lake responded to nitrogen and phosphorus limitation was not as clearly demonstrated. This difference may be a function of the amount and form of nitrogen in the runoff from the watershed of both these lakes. Our data from Itkillik Lake suggest that only 72% of the total nitrogen in that system is present in the form of particulate organic nitrogen; presumably the remaining nitrogen would be present as inorganic forms or dissolved organics and through normal cycling processes would be available to phytoplankton. Yet, we found that phytoplankton growth was better in the nitrogen treatments when compared to the phosphorus treatments. This response to nitrogen raises questions about the availability of nitrogen in Itkillik Lake and the generalization that phosphorus limitation is the rule in lakes of Gates of the Arctic National Park and Preserve. It may be that differences in vegetation and physiography within the Park result in a gradient in the amount, proportion, and form of nutrients carried by the inflows to these lakes.

Another factor contributing to the apparent difference in nutrient limitation in these two lakes may be related to morphology and thermal stratification. Itkillik Lake is shallow and thermal stratification seems to be an ephemeral condition, whereas Walker Lake is deep enough that stratification is a permanent condition throughout summer. It may be that during wind-driven mixing periods in Itkillik Lake, nutrients released into the hypolimnion by decomposition or nutrients (likely phosphorus) associated with resuspended bottom sediments may be entrained in the water column and by this internal loading mechanism provide short-term stimulation of the algae. Based on limnological studies conducted elsewhere we would anticipate that phosphorus limitation might be most prevalent during prolonged stratification, and that nitrogen limitation might occur during and following mixing.

Like most short-term studies, our work at Itkillik Lake has added to the information base on the water resources of the Park and has stimulated interesting questions about how these lakes function and what factors regulate their fertility. Our original hypothesis about phosphorus limitation of lake phytoplankton needs to be modified to account for differences in nutrient chemistry among the lakes. Perhaps these differences are related to east-west gradients in terrestrial vegetation with Gates of the Arctic National Park and Preserve. Also, it may be that lake morphometry influences internal loading processes, particularly in shallow lakes that have weak thermal stratification.

We hope to have an opportunity to test and refine these hypotheses by additional work on these lakes in the future.

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Table 1. Measurements of major ions of Itkillik Lake.

Date	Station	Depth (m)	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Alkalinity as $CaCO_3$	SO_4^{-2}-S	Cl^{-1}
			mg/L						
8 Jul 89	I	0	38.3	6.1	0.6	5.7	—	2.78	0.8
		1	37.2	6.0	0.6	5.7	—	2.97	0.8
		2	38.8	6.0	0.6	6.2	—	2.97	0.8
		4	38.8	6.0	0.6	6.0	—	3.03	0.8
		6	39.9	6.2	0.6	6.1	—	2.93	0.7
		7	—	—	—	—	—	2.98	0.6
		8	—	—	—	—	—	3.07	0.6
		9	—	—	—	—	—	2.97	0.6
		10	—	—	—	—	—	3.01	0.6
10 Jul 89	I	1	39.0	6.0	0.5	6.0	109	3.00	0.6
		3	38.5	6.0	0.5	5.9	108	2.93	0.7
		5	38.7	6.2	0.6	6.4	100	2.85	0.7
		7	39.1	6.0	0.5	5.9	100	2.89	0.6
		9	39.1	6.0	0.5	5.9	101	2.85	0.6

Table 2. Measurements of major ions of tributaries of Itkillik Lake on 10 July 1989.

Tributary	Estimated Flow (m^3)	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Alkalinity as $CaCO_3$	SO_4^{-2}-S	Cl^{-1}
		mg/L						
1	0.01	56.2	3.2	0.9	3.5	123	4.99	0.5
2	0.03	68.1	8.4	0.6	2.6	150	5.37	0.5
3	0.0003	59.1	6.0	0.3	0.9	147	2.35	0.6
4	0.09	60.7	8.0	1.2	3.1	155	4.86	0.5
5	0.06	61.1	8.5	0.4	3.5	147	5.30	0.6
6	0.06	68.8	12.4	0.6	8.1	—	5.64	0.6

Table 3. Total nitrogen, total phosphorus, silica, and chlorophyll-a of Itkillik Lake.

Date	Station	Depth (m)	TN (mg/L)	TP (μg/L)	SiO_2 (mg/L)	Chlorophyll-*a* (μg/L)
8 Jul 89	I	0	0.30	5	1.20	0.61
		1	0.34	4	1.20	0.66
		2	0.26	4	1.24	0.63
		4	0.36	9	1.28	0.59
		6	0.27	3	1.24	0.69
		7	0.26	4	1.45	0.89
		8	0.26	3	1.45	1.00
		9	0.60	6	1.49	1.53
		10	0.35	3	1.41	1.20
9 Jul 89	II	0	0.34	2	—	0.74
		2	0.30	3	—	0.58
		4	0.32	4	—	0.70
		6	0.26	4	—	0.98
		7	0.30	3	—	1.02
		8	0.26	4	—	1.12
		9	0.40	4	—	1.25
		10	0.37	7	—	1.28
10 Jul 89	I	1	0.36	4	1.45	0.79
		3	0.37	5	1.78	0.74
		5	0.31	5	1.12	0.82
		7	0.37	6	1.16	1.27
		9	0.32	5	1.53	1.67
11 Jul 89	I	0	0.31	4	—	0.93
		2	0.31	4	—	0.93
		4	0.33	4	—	1.87
		6	0.24	3	—	0.96

Table 4. Total nitrogen, total phosphorus, silica, and chlorophyll-a measurements of tributaries to Itkillik Lake, 10 July 1989.

Tributary	Estimated Flow (m^3)	TN (mg/L)	TP (µg/L)	SiO_2 (mg/L)	Chlorophyll-*a* (µg/L)
1	0.01	0.53	4	2.67	0.75
2	0.03	0.20	2	2.06	0.05
3	<0.01	0.36	8	2.55	0.57
4	0.09	0.21	1	2.43	0.08
5	0.06	0.45	3	2.26	0.08
6	0.06	0.19	2	2.14	0.10

Table 5. Temperature and dissolved oxygen profiles at Itkillik Lake.

Station I						
8 Jul 89 3:40 a.m. (ADST)		8 Jul 89 10:40 p.m. (ADST)		11 Jul 89 12 Noon (ADST)		
Depth (m)	Temp (°C)	Depth (m)	Temp (°C)	Depth (m)	Temp (°C)	D.O. (mg/L)
0	13.5	0	14.3	0	13.5	11.1
1	13.5	1	14.3	1	13.5	11.3
2	13.5	2	14.3	2	13.5	10.9
3	13.5	3	14.3	3	13.5	10.7
4	13.5	4	14.3	4	13.5	10.7
5	13.5	5	14.3	5	13.5	10.6
6	13.5	6	14.0	6	13.5	10.6
7	13.3	7	13.7	7	13.5	10.5
8	13.2	8	12.9	8	13.0	10.5
9	12.0	9	12.3	9	13.0	—
10	10.2	10	10.9	10	13.0	—
11	9.8					
12	9.0					

Station II 9 Jul 89 12 Noon (ADST)		Station III 12 Jul 89 12 Noon (ADST)		
Depth (m)	Temp (°C)	Depth (m)	Temp (°C)	D.O. (mg/L)
0	14.3	0	13.2	10.9
1	14.1	1	13.5	10.0
2	14.0	2	13.7	9.9
3	13.9	3	13.7	9.9
4	13.8	4	13.7	9.9
5	13.4	5	13.7	9.9
6	13.2	6	13.7	9.9
7	12.9	7	13.7	9.9
8	12.8	8	13.7	9.9
9	12.5	9	13.7	9.9
10	12.3	10	13.7	9.9
11	12.1			
11.5	11.6			

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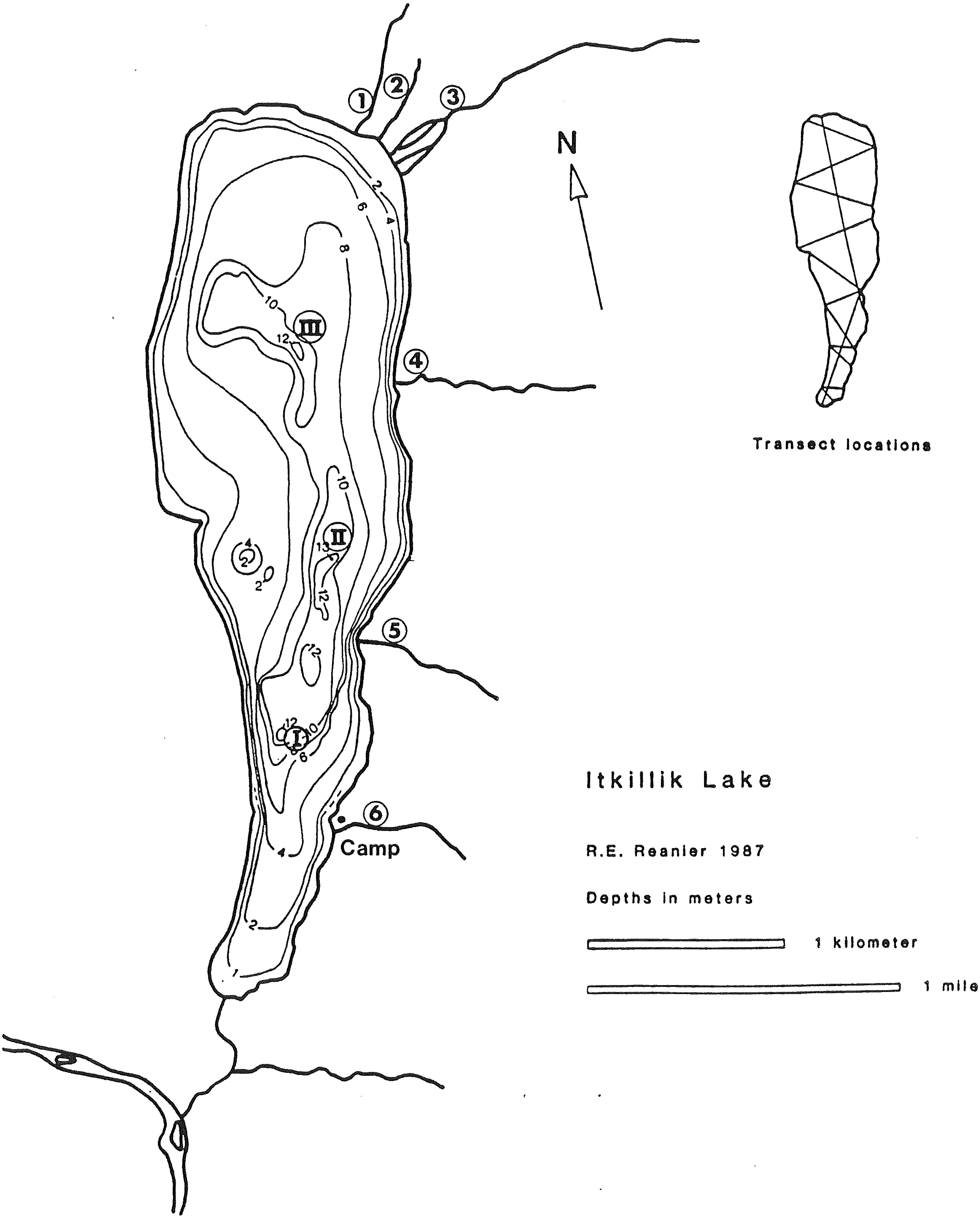

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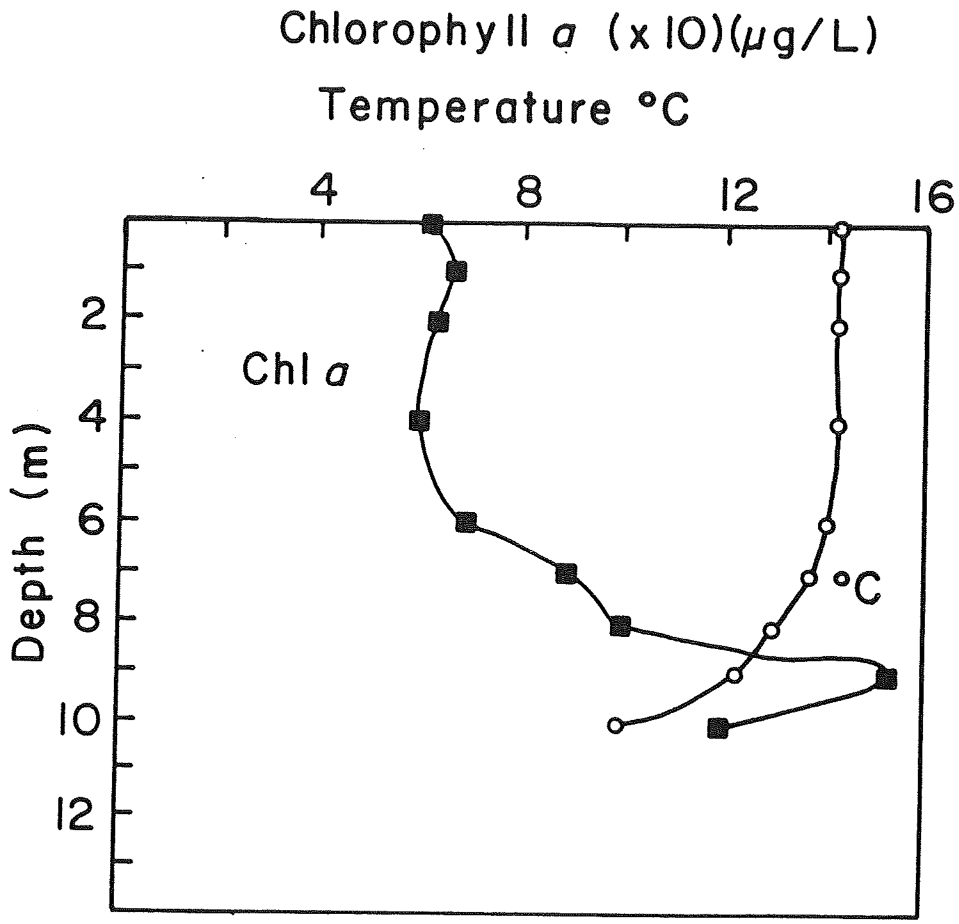
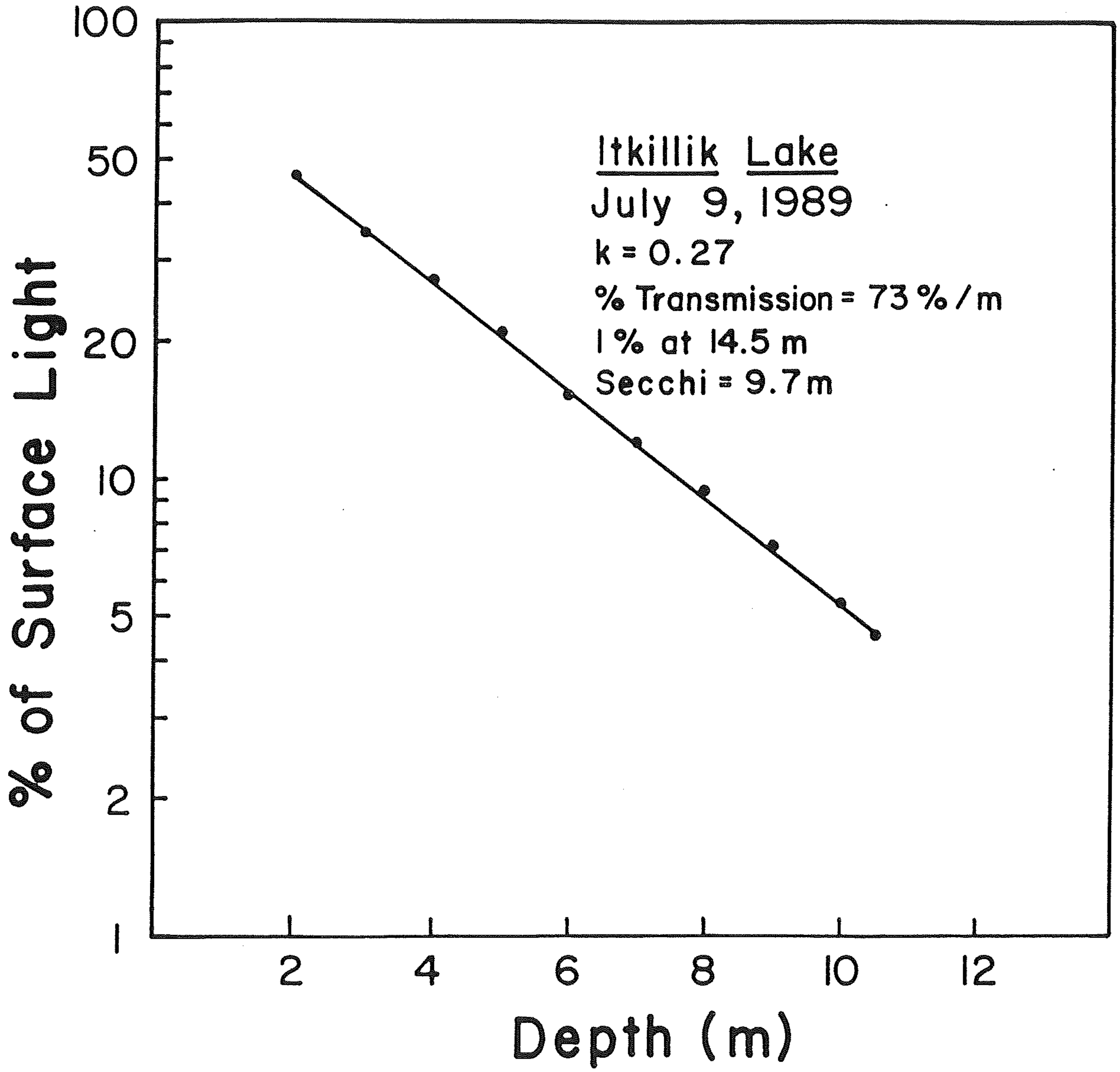
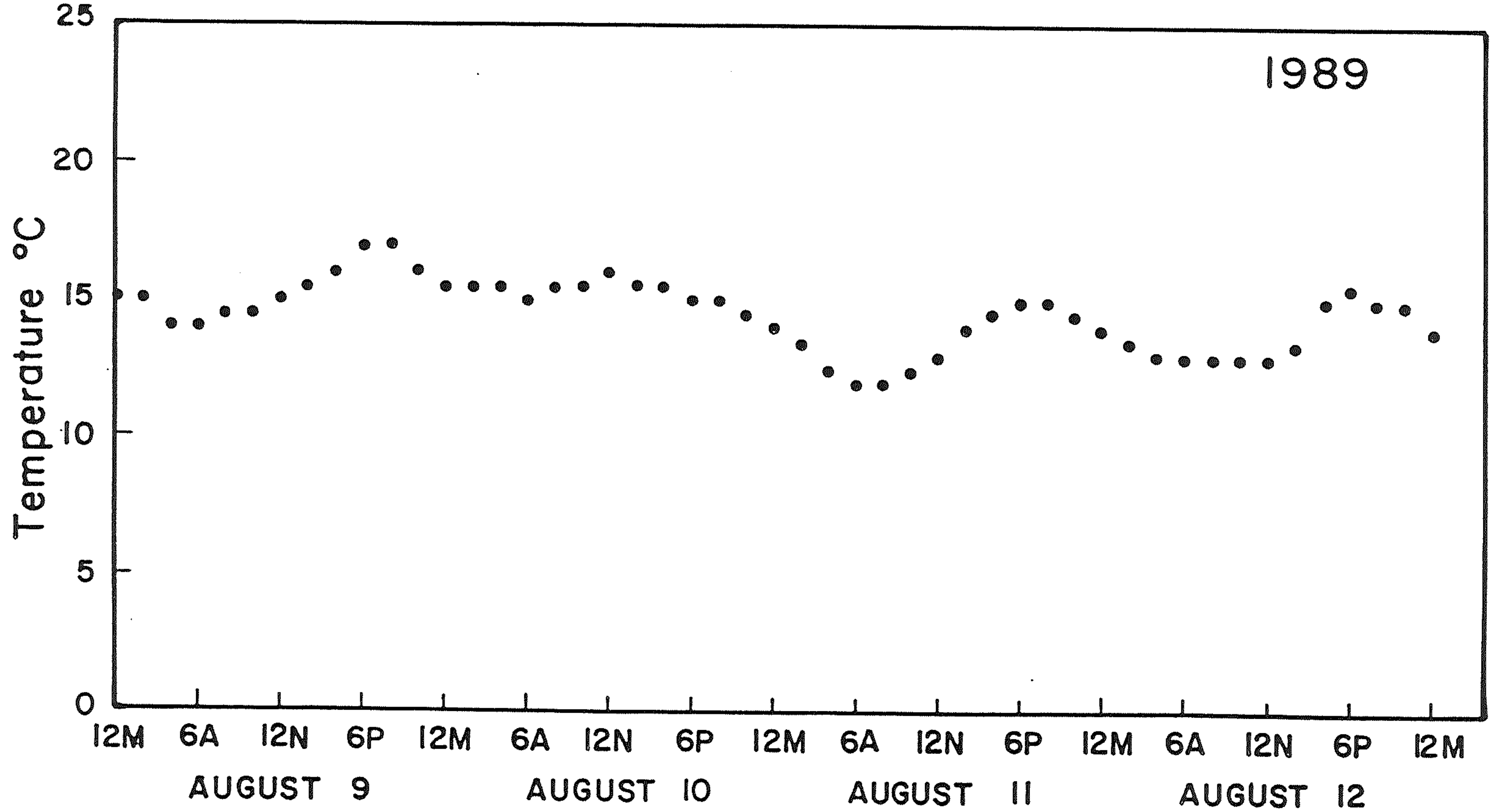
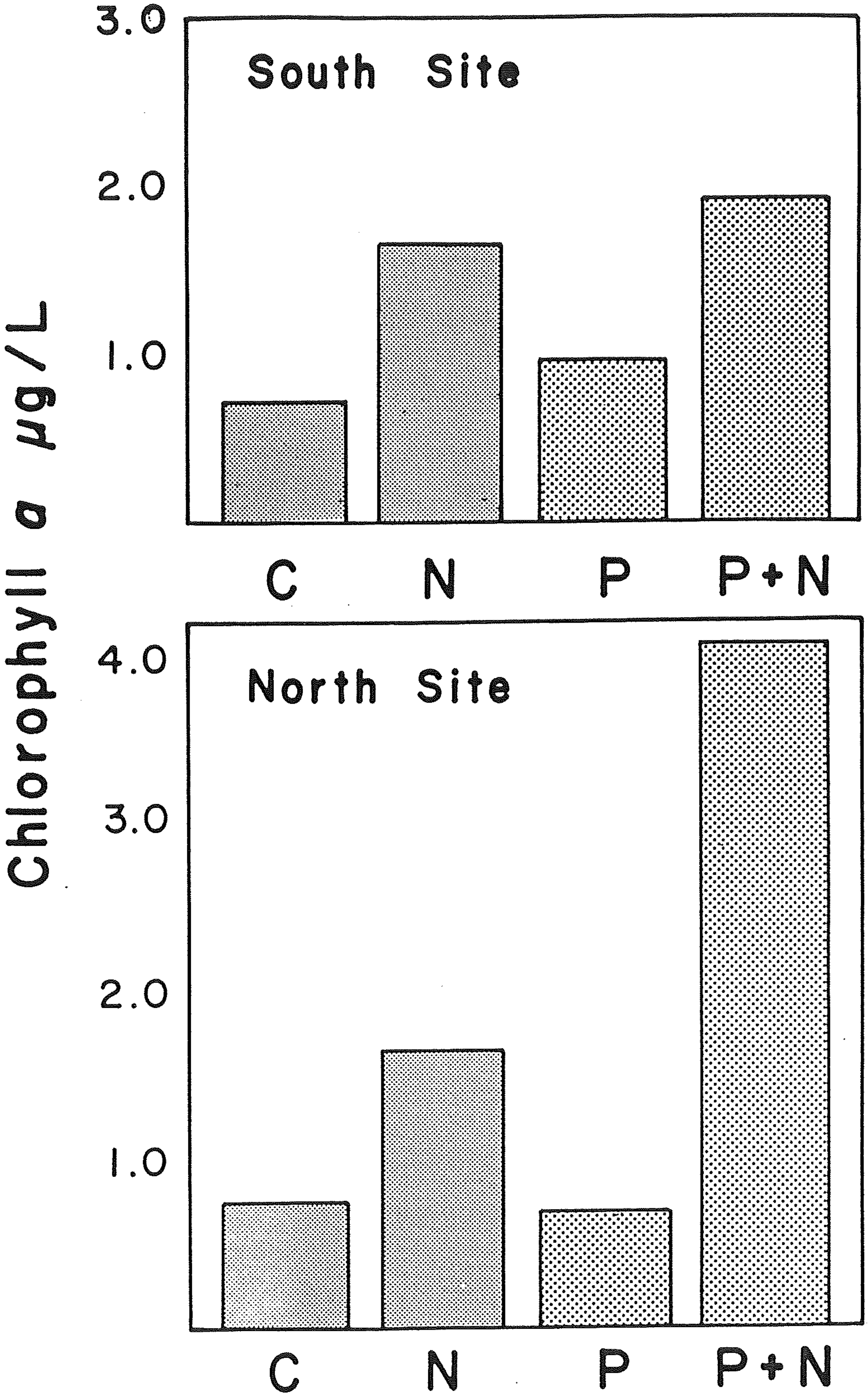
Camp
Transect locations
Itkillik Lake
R.E. Reanier 1987
Depths in meters
1 kilometer
1 mile


Chlorophyll a (x 10)(μg/L)
Temperature °C
4
8
12
16
2
4
6
8
10
12
Depth (m)
Chl a
°C


Itkillik Lake
July 9, 1989
k = 0.27
% Transmission = 73 % / m
1 % at 14.5 m
Secchi = 9.7 m
% of Surface Light
100
50
20
10
5
2
1
2
4
6
8
10
12
Depth (m)


1989
Temperature °C
0
5
10
15
20
25
12M
6A
12N
6P
12M
6A
12N
6P
12M
6A
12N
6P
12M
6A
12N
6P
12M
AUGUST 9
AUGUST 10
AUGUST 11
AUGUST 12


South Site
North Site
Chlorophyll a μg/L
3.0
2.0
1.0
4.0
3.0
2.0
1.0
C
N
P
P+N
C
N
P
P+N

Appendix 1. Raw data summary—Itkillik Lake, 1989.

Date	Station	Depth (m)	Total P (µg/L)	Total N (mg/L)	Chl-*a* (µg/L)	Phaeo-pigments (µg/L)	Nanno-chl-*a* (µg/L)	Nanno-phaeo-pigments (µg/L)	pH	Color (units)	Alkalinity (mg/L) as $CaCO_3$	SiO_2 (mg/L)
7/8/89	I	0			0.73	0.00	0.64	0.00				
		0			0.64	0.20	0.59	0.01				
		0			0.66	0.00	0.57	0.01				
	III	0			0.62	0.00	0.56	0.02				
		0			0.66	0.00	0.56	0.00				
		0			0.57	0.00	0.62	0.00				
	I	0	5	0.30	0.61	0.04	0.57	0.00				1.20
		1	4	0.34	0.66	0.02	0.58	0.02				1.20
		2	4	0.26	0.63	0.00	0.60	0.00				1.24
		4	9	0.36	0.59	0.01	0.56	0.02				1.28
		6	3	0.27	0.69	0.10	0.76	0.01				1.24
		7	4	0.26	0.89	0.00	0.87	0.05				1.45
		8	3	0.26	1.00	0.03	1.03	0.01				1.45
		9	6	0.60	1.53	0.06	1.52	0.10				1.49
		10	3	0.35	1.20	0.15	1.14	0.10				1.41
7/9/89	II	0	2	0.34	0.74	0.00						
		2	3	0.30	0.58	0.02						
		4	4	0.32	0.70	0.01						
		6	4	0.26	0.98	0.00						
		7	3	0.30	1.02	0.06						
		8	5	0.26	1.12	0.07						
		9	4	0.40	1.25	0.04						
		10	7	0.37	1.28	0.05						
		0	7	0.34	0.58	0.00						
		0	4	0.32	0.69	0.00						

Appendix 1. Continued.

Date	Station	Depth (m)	Total P (µg/L)	Total N (mg/L)	Chl-*a* (µg/L)	Phaeo-pigments (µg/L)	Nanno-chl-*a* (µg/L)	Nanno-phaeo-pigments (µg/L)	pH	Color (units)	Alkalinity (mg/L) as $CaCO_3$	SiO_2 (mg/L)
7/10/89	I	1	4	0.36	0.79	0.00			8.57		109	1.45
		3	5	0.37	0.74	0.03			8.46		108	1.78
		5	5	0.31	0.82	0.13			8.36		100	1.12
		7	6	0.37	1.27	0.27			8.37		100	1.16
		9	5	0.32	1.67	0.07			8.35		101	1.53
	1	0	4	0.53	0.75	0.16			8.23	25	123	2.67
	2	0	2	0.20	0.05	0.00			7.87	20	150	2.06
	3	0	8	0.36	0.57	0.14			7.47	30	147	2.55
	4	0	1	0.21	0.08	0.00			8.06	15	155	2.43
	5	0	3	0.45	0.08	0.00			7.98	20	147	2.26
	6	0	2	0.19	0.10	0.04			7.93	20		2.14
7/11/89	I	0	4	0.31	0.93	0.01			8.47			
		2	4	0.31	0.93	0.03			8.47	10		
		4	4	0.33	0.87	0.01			8.49	10		
		6	3	0.24	0.96	0.03			8.47			
	*	0	5	0.36	0.87	0.04	0.70	0.02	8.19			1.28
7/12/89	III	0	4	0.28	0.78	0.02						
	II	0	5	0.38	0.96	0.00						
7/13/89	I	0	6	0.46	0.89	0.01						
		0	5	0.38	0.77	0.04						
		0	6	0.32	0.78	0.02						

* Outlet stream.

Appendix 2. Raw data summary—Itkillik Lake, 1989.

Date	Station	Depth (m)	Temp. (°C)	Dissolved O_2 (mg/L)	Secchi depth (m)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	Cl^{-1} (mg/L)	SO_4^{-2}-S (mg/L)	Cond. (µS/cm)
7/8/89	I	0	13.5	11.2	9.7							
		0	13.5	11.2	9.7							
		0	13.5	11.2	9.7							
	III	0										
		0										
		0				38.3	06.1	0.6	5.7			
	I	0	14.3	11.9	9.6	37.2	06.0	0.6	5.7	0.8	2.78	239
		1	14.3	11.9		38.8	06.0	0.6	6.2	0.8	2.97	246
		2	14.3	11.9		38.8	06.0	0.6	6.0	0.8	2.97	243
		4	14.3	11.8		39.9	06.2	0.6	6.1	0.8	3.03	242
		6	14.0	12.0						0.7	2.93	247
		7	13.7	12.1						0.6	2.98	243
		8	12.9	12.1						0.6	3.07	248
		9	12.3	12.1						0.6	2.97	249
		10	10.9	10.1						0.6	3.01	250
7/9/89	II	0	14.3									
		2	14.0									
		4	13.8									
		6	13.2									
		7	12.9									
		8	12.8									
		9	12.5									
		10	12.3									
		0										
		0										

Appendix 2. Continued.

Date	Station	Depth (m)	Temp. (°C)	Dissolved O_2 (mg/L)	Secchi depth (m)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Cl^{-1} (mg/L)	SO_4^{-2}-S (mg/L)	Cond. (µS/cm)
7/10/89	I	1				39.0	06.0	0.5	6.0	0.6	3.00	244
		3				38.5	06.0	0.5	5.9	0.7	2.93	243
		5				38.7	06.2	0.6	6.4	0.7	2.85	242
		7				39.1	06.0	0.5	5.9	0.6	2.89	241
		9				39.1	06.0	0.5	5.9	0.6	2.85	244
	I	0				56.2	03.2	0.9	3.5	0.5	4.99	308
	2	0				68.1	08.4	0.6	2.6	0.5	5.37	397
	3	0				59.1	06.0	0.3	0.9	0.6	2.35	334
	4	0				60.7	08.0	1.2	3.1	0.5	4.86	36.5
	5	0				61.1	08.5	0.4	3.5	0.6	5.30	365
	6	0				68.8	12.4	0.6	8.1	0.6	5.64	420
7/11/89	I	0	13.5	11.4								
		2	13.5	11.1								
		4	13.5	11.0								
		6	13.5	10.9								
	*	0				38.6	06.0	0.6	5.8	0.9	3.37	249
7/12/89	III	0										
	II	0										
7/13/89	I	0										
		0										
		0										

* Outlet stream.